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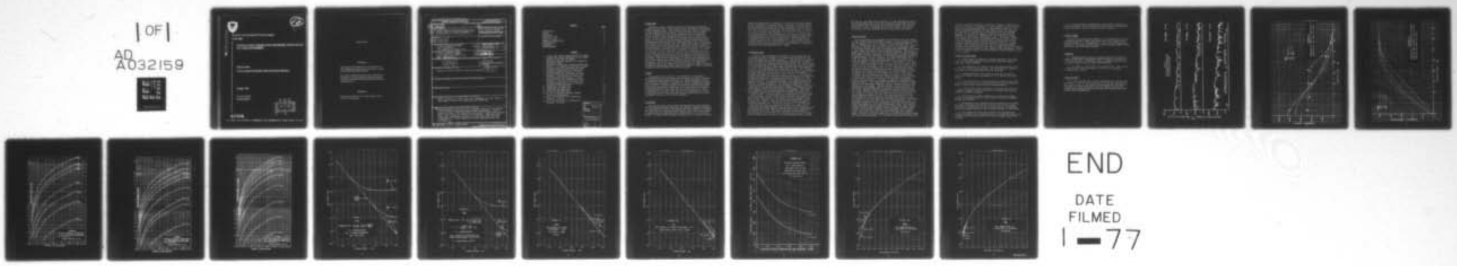

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Research and Development Technical Report

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EXPECTED DIGITAL TRANSMISSION PERFORMANCE DURING MOTION IN A JUNGLE ENVIRONMENT

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October 1976

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number):

Fading measurements were made from information available on the behavior of a VHF carrier propagating through a jungle environment. A determination was made of the fading rates that could be expected when relative motion exists between the receiver and transmitter. Based upon these fading rates, predictions are made of the bit error rates that could be expected from a VRC-12 communication system operating in the test environment.

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CONTENTS

FIGURES

INTRODUCTION

Distortion of radio signals resulting from fading and multipath transmissions presents a serious obstacle for achieving and maintaining reliable communications. The resultant signal at a point is formed by the superposition of the multipath signals arriving with differing phases. Communications in a jungle environment can be especially serious because of the changing path structure due to position and because of the multipath caused by reflections and scattering from the trees. In the case of tactical ground to ground communications, the transmitter and receiver may be at fixed locations or one or both may be in motion. In the former case, the transmission paths are relatively fixed and if signal reception is poor, absent, or severely distorted, then moving one or both positions may sufficiently alter the basic path and the multipath structure so that reception is improved. The mobile case presents a dynamic situation, whereby the transmission paths are continuously varying so that the resultant fading and multipath interference pattern at the receiver causes the signal to fade and reappear so long as relative motion between the receiver and the transmitter is maintained. The effect of the rapidity of fading on the expected error rate at the receiver will depend upon the rate at which information is transmitted. The error rate, for narrow band low rate information transmission such as for voice, will be less than for a high rate digital information transmission system, where the rapidity of fading causes more frequent loss of coherence of the digital pulses.

PURPOSE

The purpose of this report is to determine data transmission performance based upon the fading characteristics that can be expected for a communications system operating in a jungle environment at VHF. In addition to determining the probability density function associated with the depth of fading, a projection is made to determine the fading rates that can be anticipated when relative motion exists between the receiver and transmitter. Based upon the fading rates, it is desired to determine the bit error rates that can be expected for the transmitter-receiver used during the test and then to extrapolate the data to determine the bit error rates that can be anticipated from a VRC-12 operating at 40 watts in the test environment.

DESCRIPTION

The data contained in this report was derived from analog records taken by Stanford Research Institute near Chumphon, Thailand (Reference 1). The area is a tropical rain forest with a mean height of 12 meters, and 90% of the trees are less than 27 meters high. Most of the forest is covered with an undergrowth of broad-leaf plants 2 to 3 meters in height. The forest floor usually is covered by 3 to 10 inches of water.

The data was taken with a receiver, at a fixed site, located approximately .15 miles in a clearing outside the jungle. The power output of the transmitter was about .35 watts, radiating CW signals simultaneously or in pulsed sequence on three frequencies - 50, 75 and 100 MHz. The transmitter was manpacked and moved deeper into the jungle, with signal strength being recorded at the receiver at known incremental displacements of the transmitter. The data used in this report was obtained with the receiver and transmitter antennas oriented for horizontal polarization. The receiver noise (0 dB) corresponded to .7 microvolts across the 50 ohm antenna load. The strength of the received signals at 50, 75 and 100 MHz, as a function of the distance between the receiver and transmitter is shown in Figure 1, which is a portion of the record between 0 and .6 miles.

REDUCTION OF DATA

At each 12 foot incremental displacement of the transmitter into the jungle the signal strength at the receiver was measured from an analog recording such as shown in Figure 1. Each reading was converted from dB to microvolts and the average signal strength, over approximately 120 feet, was calculated and converted back to dB. The dB scale on the recording was not linear, hence the scale was calibrated by means of a staircase calibrating signal which indicated the linear displacement from 0 dB corresponding to a particular dB level. The position, as well as the depth of each fade in dB, from the average was determined. The total number of fades between .15 and .6 miles were ordered to determine the number of fades 0 dB, 1 dB, 2 dB, etc. A relative frequency density histogram was then normalized and smoothed to obtain the probability density as a function of the depth of fade in dB. This was done for each of the three frequencies. The resultant plots are shown in Figure 2. The probability distribution curves, derived from Figure 2, are shown in Figure 3. In order to determine the fading rates that could be expected in this environment caused by a person or vehicle moving through the jungle with a receiver or transmitter, the total number of fades per unit distance was determined. This information coupled with the assumed velocity, provided the fading rate. The analysis assumed that the fades were uniformly distributed between .15 and .6 miles. The fading rates as a function of the transmitter/receiver velocity, for 50, 75 and 100 MHz, are shown in Figures 4, 5 and 6, where the parameter is the number of fades exceeding a given number of dB. Figures 7 and 8 are theoretical curves which show the expected error rates as a function of the S/N for DPSK and FSK respectively (Reference 2). The curves of Figure 9 are for DPSK based upon the observed fades and calculated fading rates, where it was assumed that the fading bandwidth (FB) was equal to the fading rate and the information bit rate (BR) was 1200 bits per second, commensurate with that of the VRC-12. The curves of Figure 10 are similiar to those of Figure 9, but for FSK, the "radius of gyration" of the noise band of Figure 8 was set equal to half the mark-space shift, D, which

was 1200 Hz. The lower curve of Figure 11 is the experimental curve of S/N versus distance for the .35 watt transmitter used during the test and the upper curve represented the S/N versus distance that would be expected if a VRC-12, operating at 40 watts was used. The vertical separation is 21 dB, determined from the ratio of the two powers.

ANALYSIS OF DATA

For the particular run analyzed it was found that the total number of fades increased with increasing frequency. As the transmitter moved into the jungle, from .15 to .6 miles, the corresponding number of fades at the receiver were 117 fades at 50 MHz, 147 fades at 75 MHz and 189 fades at 100 MHz. This does not appear to be unreasonable since at the higher frequencies, for a given multipath displacement, the change in phase angle will increase with increasing frequency. The greater change in phase angle will result in greater distortion and consequently more fading. Figure 2 shows that the probability of a depth of fade up to approximately 10 dB is greater for the lower frequencies, and above 10 dB the reverse is true. Likewise, in Figure 3 the slope of the curves is greater at the lower frequencies up to a depth of fade of 10 dB and beyond 10 dB the reverse is true. From Figure 3 it is also seen that 50% of the depths of fades are equal to or less than 7 dB at 50 MHz, 8 dB at 75 MHz and 11 dB at 100 MHz. From the record of Figure 1, plus two others, extending from .15 to .6 miles into the jungle, the number and depths of fades was measured and the number of fades exceeding a given level was determined. The expected number of fades per second as a function of the assumed speed, for a given signal frequency, can be determined from Figures 4, 5 and 6. For example, at 50 MHz, the number of fades per second, exceeding 17 dB, that can be expected for a relative velocity of 12 miles per hour between receiver and transmitter is .06 fades per second or approximately 4 fades per minute. Since measurements showed that the number of fades increased with increasing frequency, then the fading rate should also increase in a like manner. The above example, for frequencies of 75 and 100 MHz yields fading rates of .095 and .25 fades per second respectively. Figures 7 and 8 are theoretical curves of the bit error rate versus S/N under fading conditions for DPSK and FSK respectively. They indicate the effect that the medium has on the bit error rate. When no dispersion exists, FB = 0, the transmitted carrier will be received with no change (spread) in frequency, therefore, the only contribution to the error rate will be caused by the noise. Increasing the signal to noise ratio will result in a decreased error rate. A dispersive medium will cause a broadening of the spectrum of received signal with respect to that of the transmitted signal. The result is a fading bandwidth (FB) no longer equal to zero. Under these circumstances, as the signal to noise is increased beyond a certain point the bit error rate will level off at an irreducible level. Figures 9 and 10 are curves which were calculated based upon the observed number of fades for a 50 MHz carrier when relative motion exists between the receiver and transmitter. At the higher velocities the fading rate,

and hence the fading bandwidth is increased. Figure 11 shows that at close distances, say .125 miles, the expected signal to noise ratio for the VRC-12 is approximately 60 dB. At this distance there is a 1.5 order of magnitude difference for DPSK (Fig 9) in the bit error rate as a function of velocity with an irreducible error rate becoming apparent. At .6 miles the signal to noise ratio is 30 dB and the expected bit error rate is independent of the velocities as shown, being signal power limited and becoming larger. The curve of Figure 11 is falling at the rate of approximately 12 dB per octave, and at 1 mile the expected signal to noise ratio would be 20 dB. At this distance the resultant bit error rate would be 9.10^{-3} or 1 error in 110 bits. This would indicate that a VRC-12, transmitting digital information and operating at 40 watts and at 50 MHz, would be restricted to relatively short distances in the Chumphon jungle environment. The bit error rate versus frequency for DPSK and FSK are shown in figures 12 and 13 respectively.

SUMMARY AND CONCLUSIONS

1. In the jungle environment at Chumphon, Thailand it was noted that the higher the operating frequency, the greater the number of fades over a given distance.

2. The probability of a depth of fade below approximately 10 dB was greater at the lower frequencies. The probability of a depth of fade above 10 dB increased with increasing frequency.

3. Approximately 50% of the depths of fades are less than or equal to 7, 8 and 11 dB at frequencies of 50, 75 and 100 MHz respectively.

4. For a given relative velocity between the receiver and transmitter and for a depth of fade exceeding a given level, the number of fades per second will increase with increasing frequency.

5. If at a given location reception is poor, then the receiver/transmitter should be moved a few meters, in a random direction, in an effort to improve reception.

6. If the receiver and/or transmitter is in motion and fading produces unacceptable reception, then lowering the carrier frequency may improve reception.

7. Dispersion of the transmitted signal introduced by the medium will cause a departure from the bit error rate due to slow fading. The result is a leveling off of the bit error rate to an irreducible value as the signal to noise ratio is increased beyond a certain level.

8. The expected bit error rate resulting from the dispersive nature of the medium in an environment such as the Chumphon jungle could severely limit the range at which a VRC-12 can transmit digital data reliably.

9. It is noted that a communication system, while in motion, at velocities greater than 24 miles per hour would result in irreducible error rates greater than that shown in Figures 9 and 10.

RECOMMENDATIONS

In view of the extrapolated predicted poor performance for digital transmission through a jungle environment, due to the variable path loss and motion, it is recommended that a full scale investigation be undertaken to actually transmit digital signals through a jungle medium and evaluate the performance directly.

REFERENCES

1. Stanford Research Institute, Technical Report 36, "Selected Examples of VHF Signal Propagation Records in Tropical Terrains", by N. K. Shrauger and E. M. Kreinberg, 1967. Prepared for the US Army Electronics Command, Contract DA36-039-AMC-00040(E).

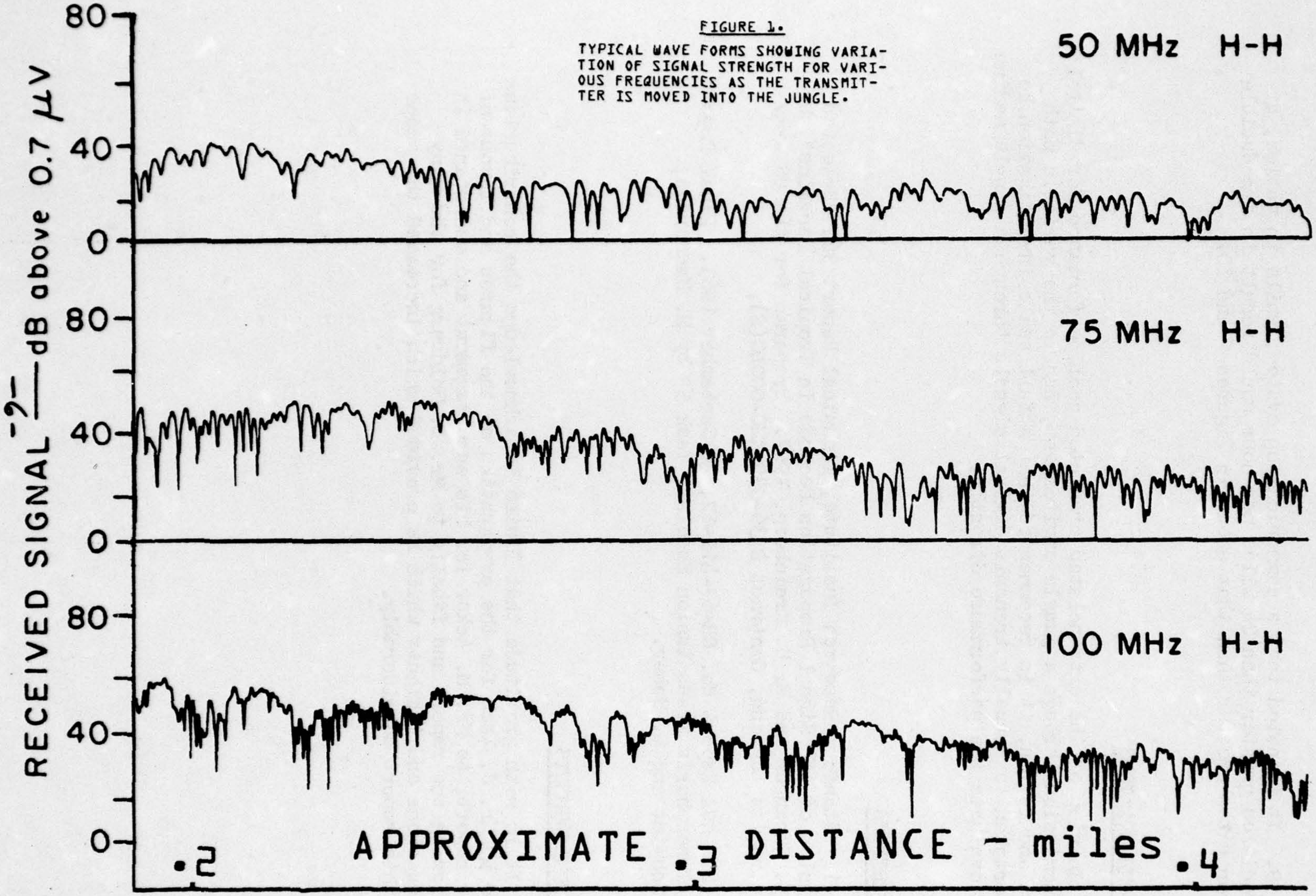
2. RCA Report No. CR-63-419-12, 30 September 1963. Final Report on "Ionospheric Transmission Models - Task 5" by M. Mansonson, A. Schmidt and S. Weber.

ACKNOWLEDGMENTS

It is with gratitude that I wish to acknowledge the contributions made by Mr. J. Koch for the preparation of the figures and layout of this report, to Mr. M. Acker for his encouragement and assistance in reviewing the report and finally to Mr. B. Goldberg for the many discussions and insights which he provided which increased the scope of this report considerably.

FIGURE 1.

TYPICAL WAVE FORMS SHOWING VARIATION OF SIGNAL STRENGTH FOR VARIOUS FREQUENCIES AS THE TRANSMITTER IS MOVED INTO THE JUNGLE.



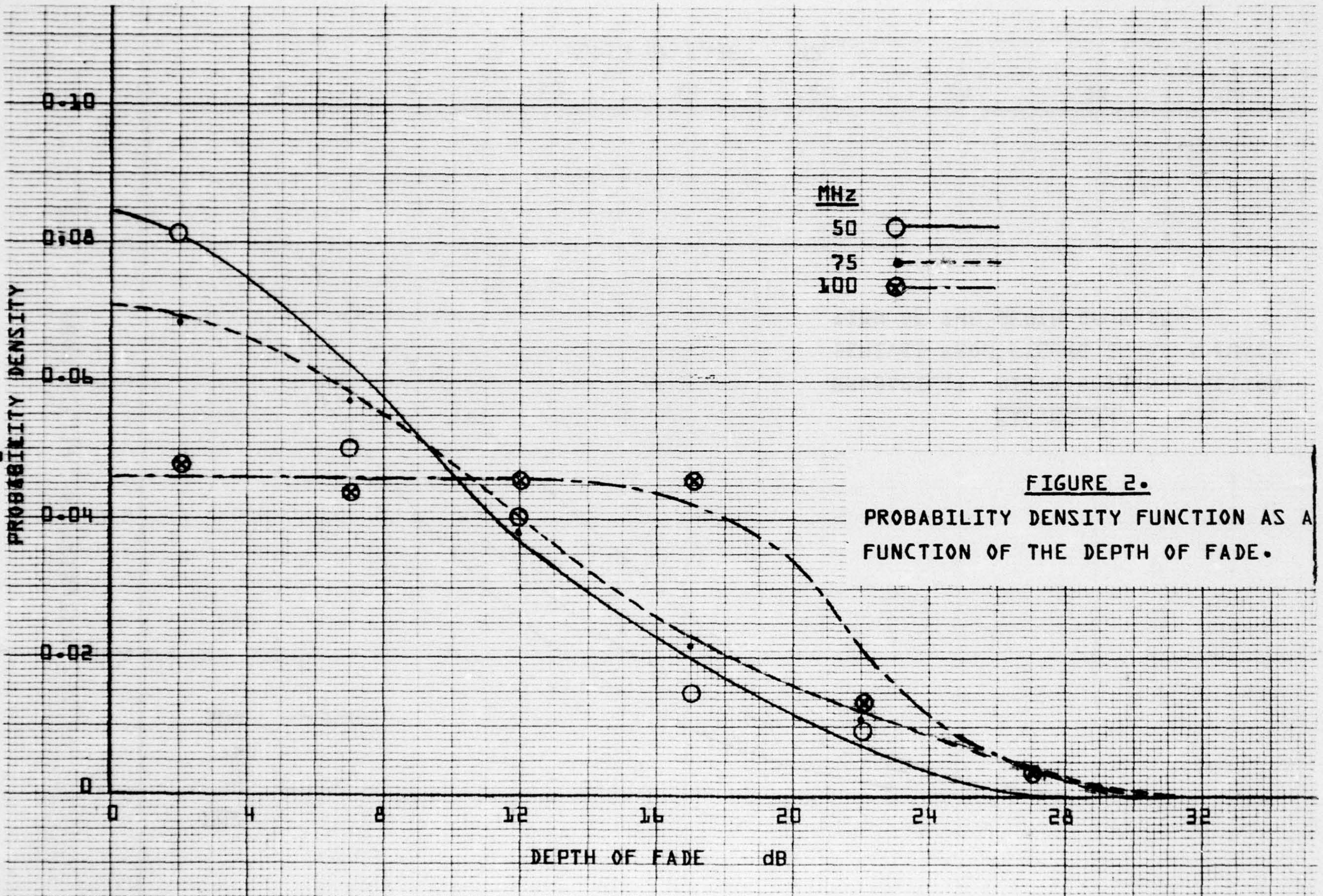


FIGURE 2.

PROBABILITY DENSITY FUNCTION AS A FUNCTION OF THE DEPTH OF FADE.

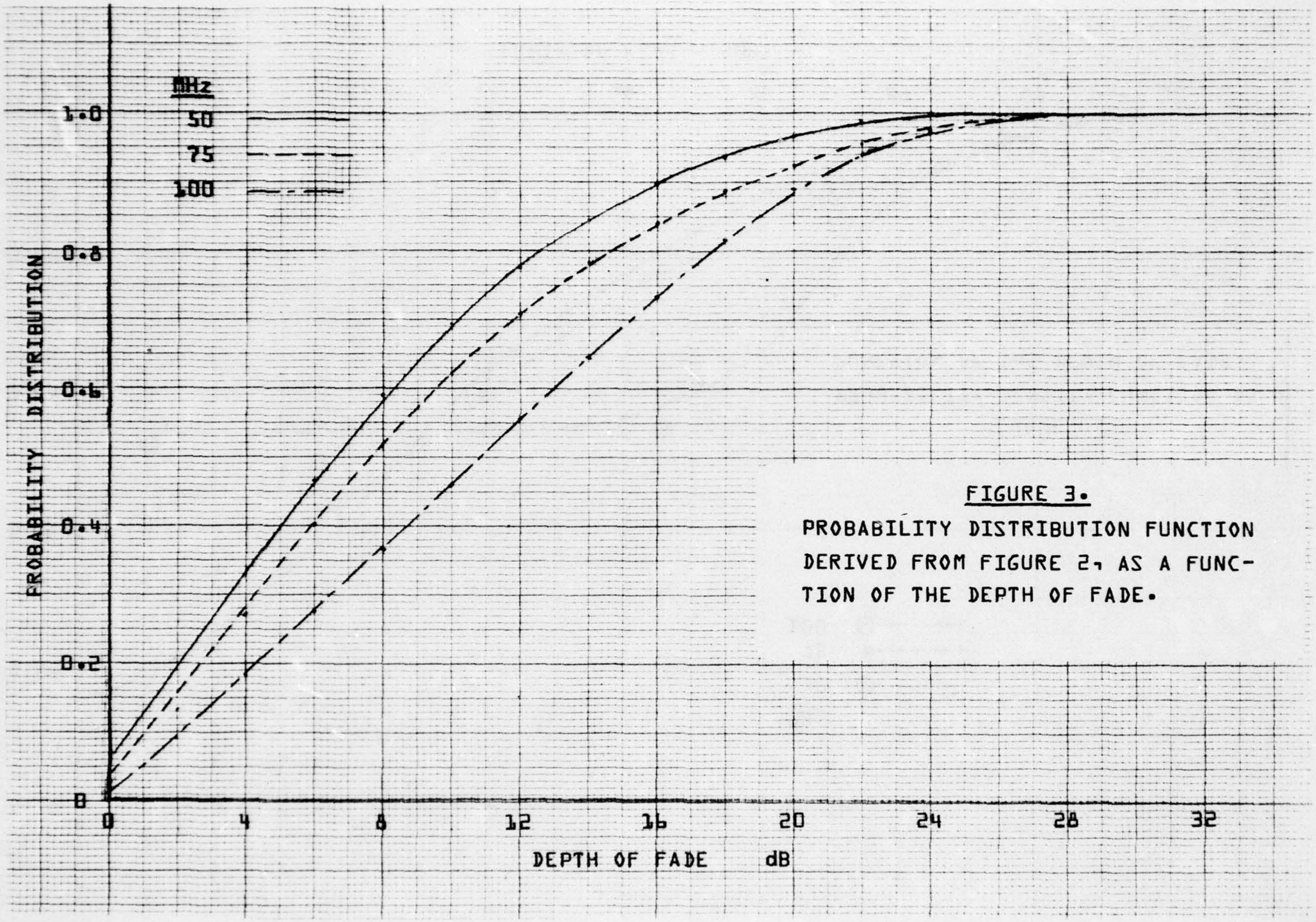


FIGURE 3.

PROBABILITY DISTRIBUTION FUNCTION DERIVED FROM FIGURE 2, AS A FUNCTION OF THE DEPTH OF FADE.

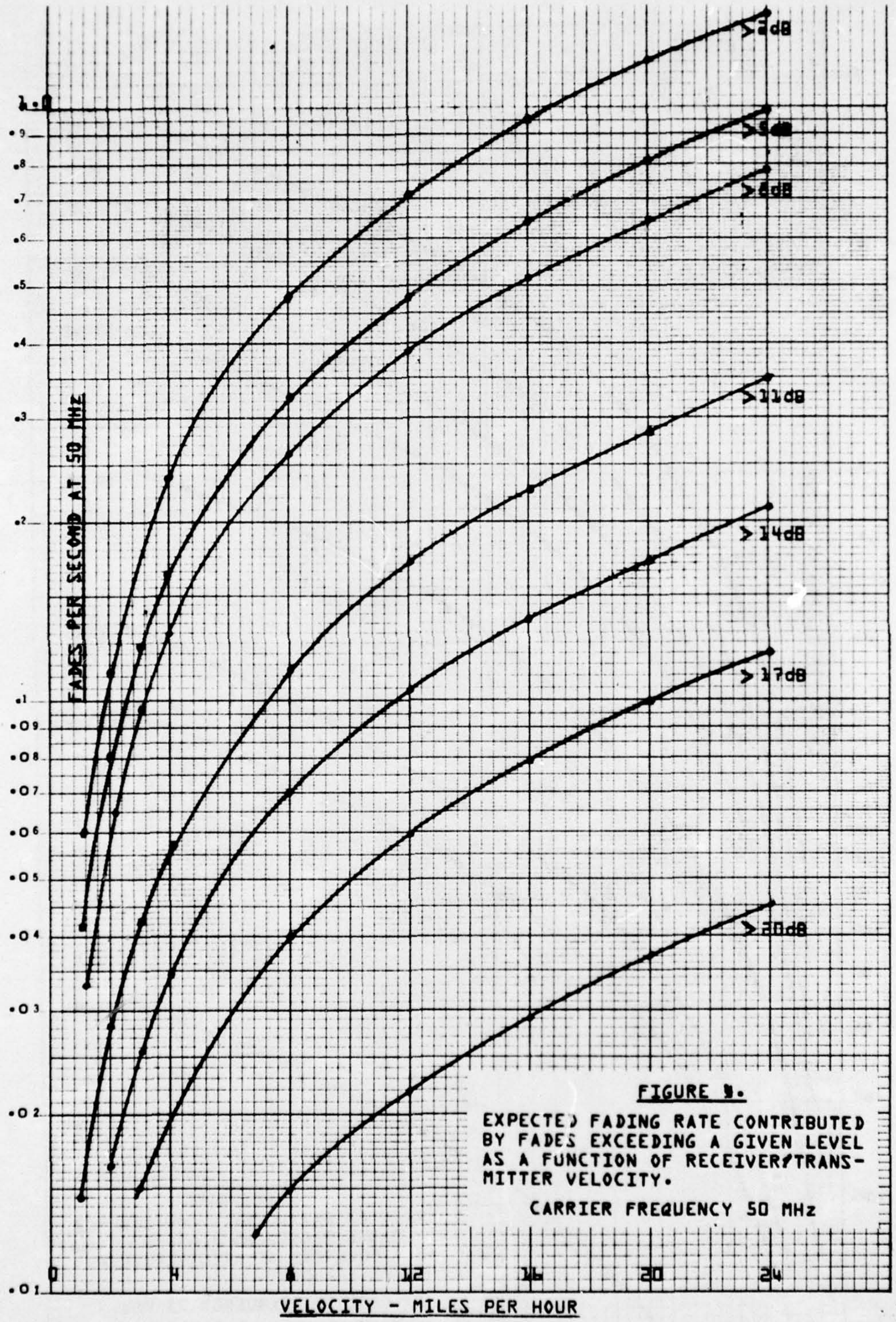


FIGURE 9.

EXPECTED FADING RATE CONTRIBUTED BY FADES EXCEEDING A GIVEN LEVEL AS A FUNCTION OF RECEIVER/TRANSMITTER VELOCITY.

CARRIER FREQUENCY 50 MHz

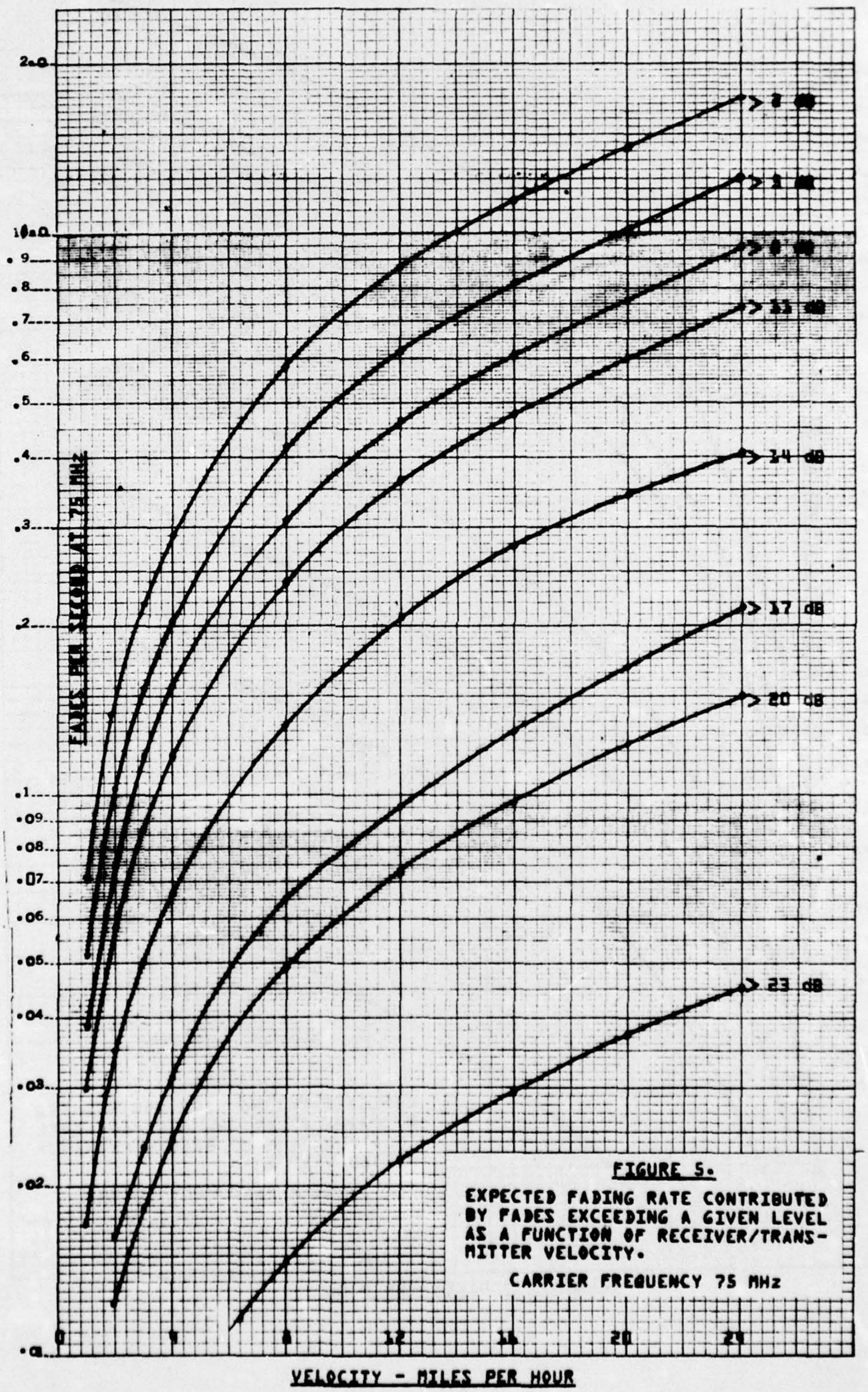


FIGURE 5.

EXPECTED FADING RATE CONTRIBUTED BY FADES EXCEEDING A GIVEN LEVEL AS A FUNCTION OF RECEIVER/TRANSMITTER VELOCITY.

CARRIER FREQUENCY 75 MHz

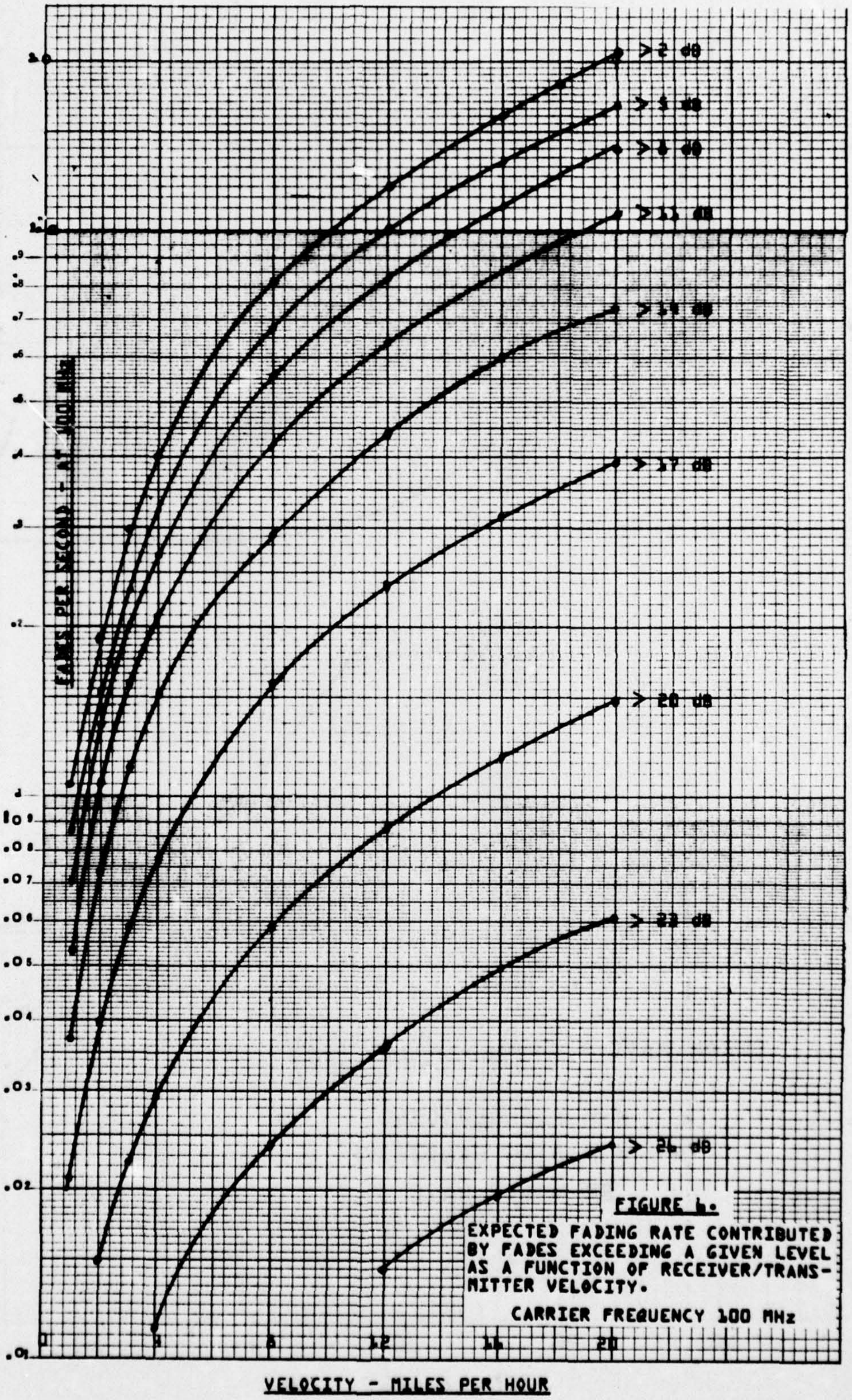
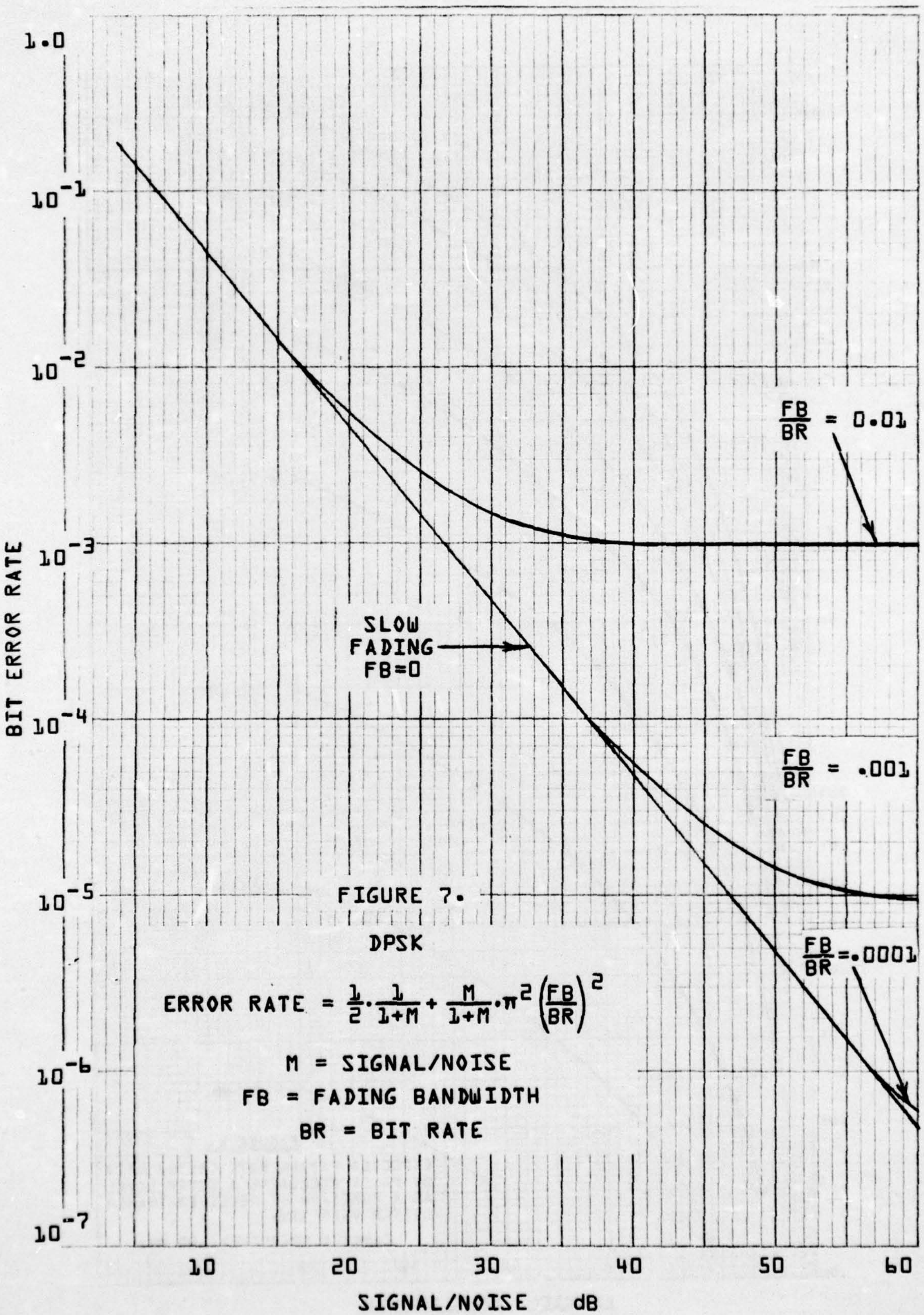


FIGURE 4.

EXPECTED FADING RATE CONTRIBUTED BY FADES EXCEEDING A GIVEN LEVEL AS A FUNCTION OF RECEIVER/TRANSMITTER VELOCITY.

CARRIER FREQUENCY 100 MHz



1.0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
BIT ERROR RATE
$\frac{FB}{BR} = 0.01$
SLOW FADING FB=0
$\frac{FB}{BR} = .001$
FIGURE 7.
DPSK
$\frac{FB}{BR} = .0001$
ERROR RATE $= \frac{1}{2} \cdot \frac{1}{1+M} + \frac{M}{1+M} \cdot \pi^2 \left(\frac{FB}{BR}\right)^2$
M = SIGNAL/NOISE
FB = FADING BANDWIDTH
BR = BIT RATE
10
20
30
40
50
60
SIGNAL/NOISE dB

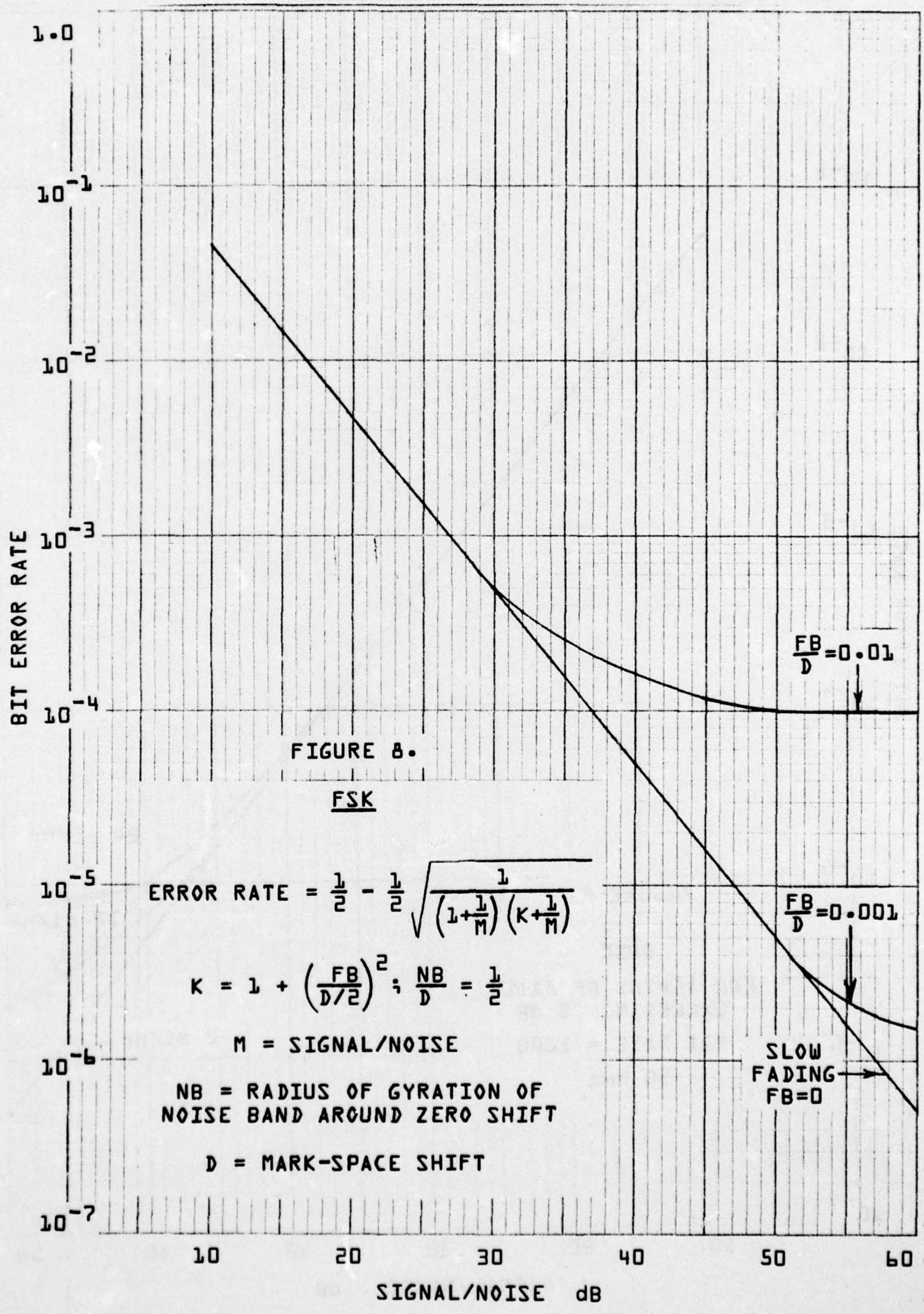


FIGURE 8.

FSK

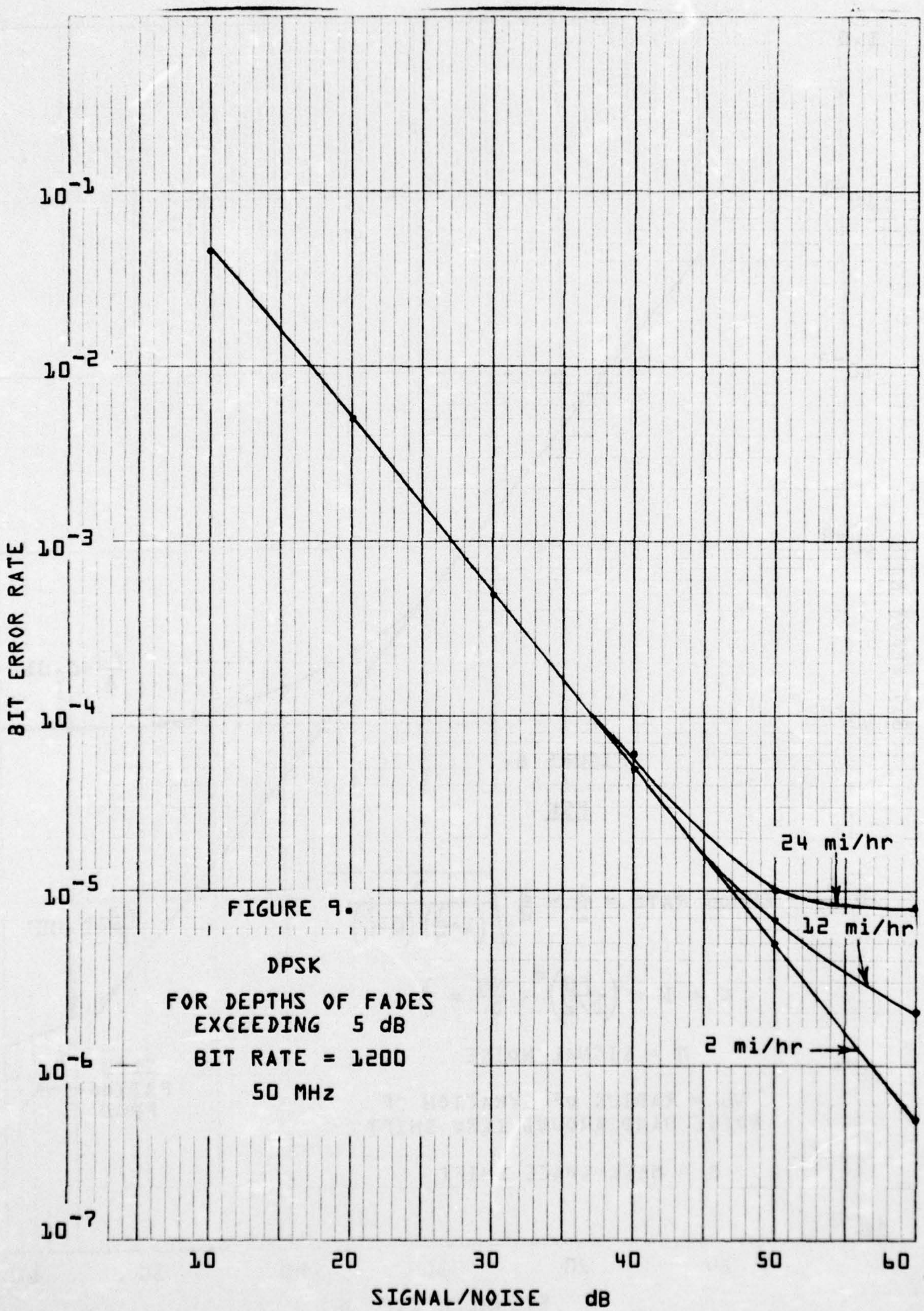
$$\text{ERROR RATE} = \frac{1}{2} - \frac{1}{2}\sqrt{\frac{1}{\left(1+\frac{1}{M}\right)\left(K+\frac{1}{M}\right)}}$$

$$K = 1 + \left(\frac{FB}{D/2}\right)^2 ; \quad \frac{NB}{D} = \frac{1}{2}$$

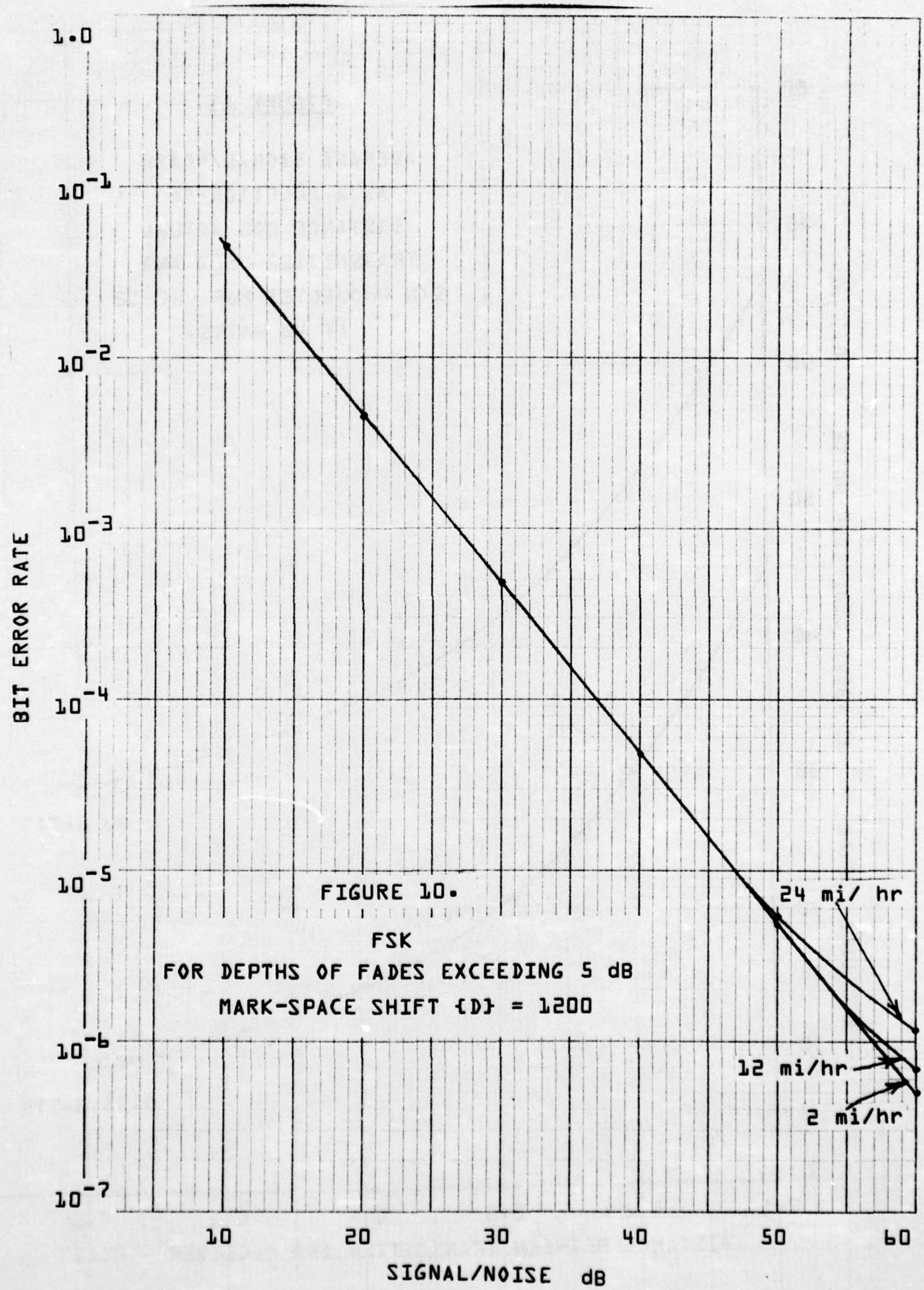
M = SIGNAL/NOISE

NB = RADIUS OF GYRATION OF NOISE BAND AROUND ZERO SHIFT

D = MARK-SPACE SHIFT



BIT ERROR RATE
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10
20
30
40
50
60
SIGNAL/NOISE dB
24 mi/hr
12 mi/hr
2 mi/hr
FIGURE 9.
DPSK
FOR DEPTHS OF FADES
EXCEEDING 5 dB
BIT RATE = 1200
50 MHz


1.0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
BIT ERROR RATE
10
20
30
40
50
60
SIGNAL/NOISE dB
24 mi/ hr
12 mi/hr
2 mi/hr
FIGURE 10.
FSK
FOR DEPTHS OF FADES EXCEEDING 5 dB
MARK-SPACE SHIFT {D} = 1200

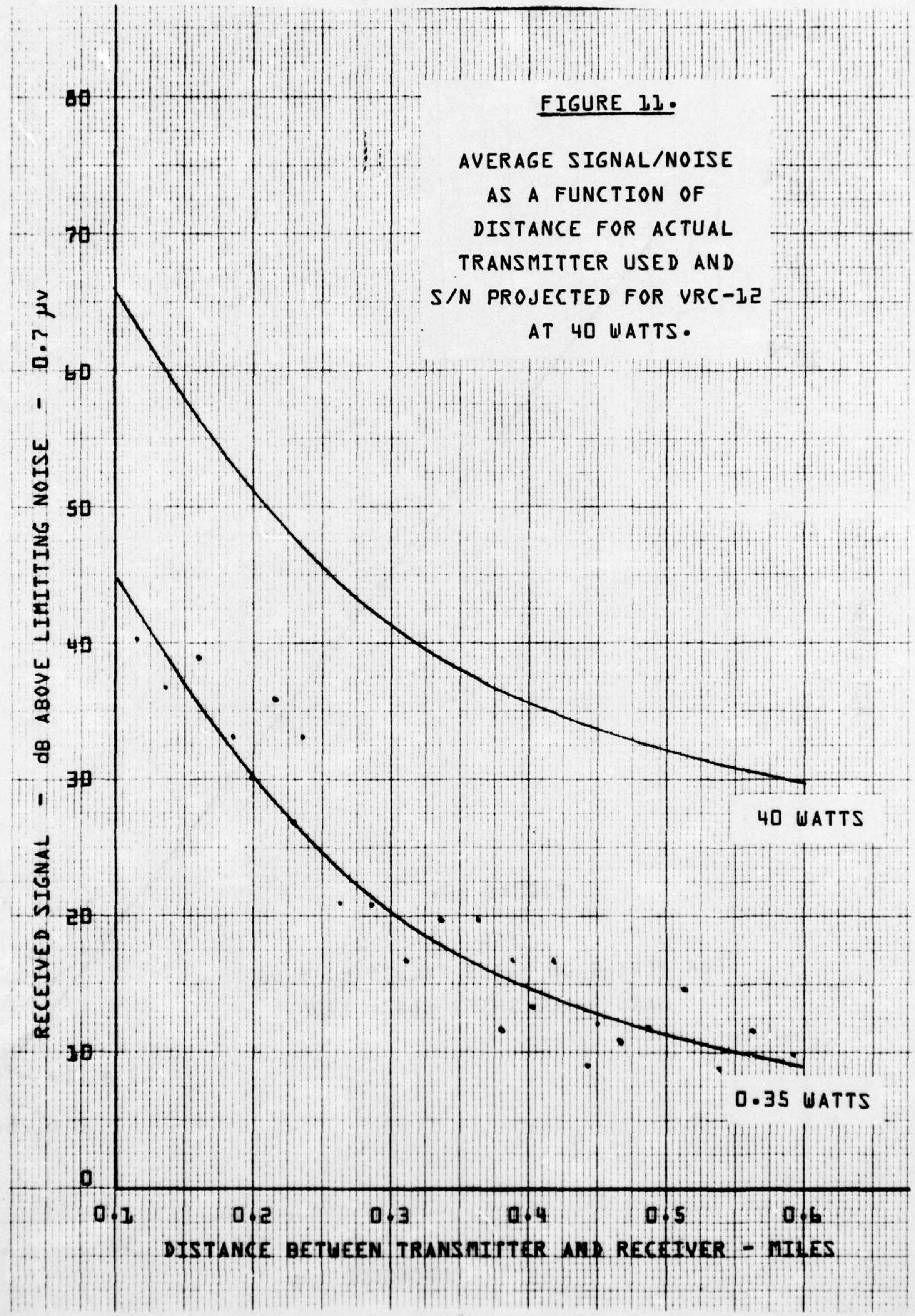


FIGURE 11.
AVERAGE SIGNAL/NOISE
AS A FUNCTION OF
DISTANCE FOR ACTUAL
TRANSMITTER USED AND
S/N PROJECTED FOR VRC-12
AT 40 WATTS.
40 WATTS
0.35 WATTS
RECEIVED SIGNAL - dB ABOVE LIMITTING NOISE - 0.7 µv
80
70
60
50
40
30
20
10
0
0.1
0.2
0.3
0.4
0.5
0.6
DISTANCE BETWEEN TRANSMITTER AND RECEIVER - MILES

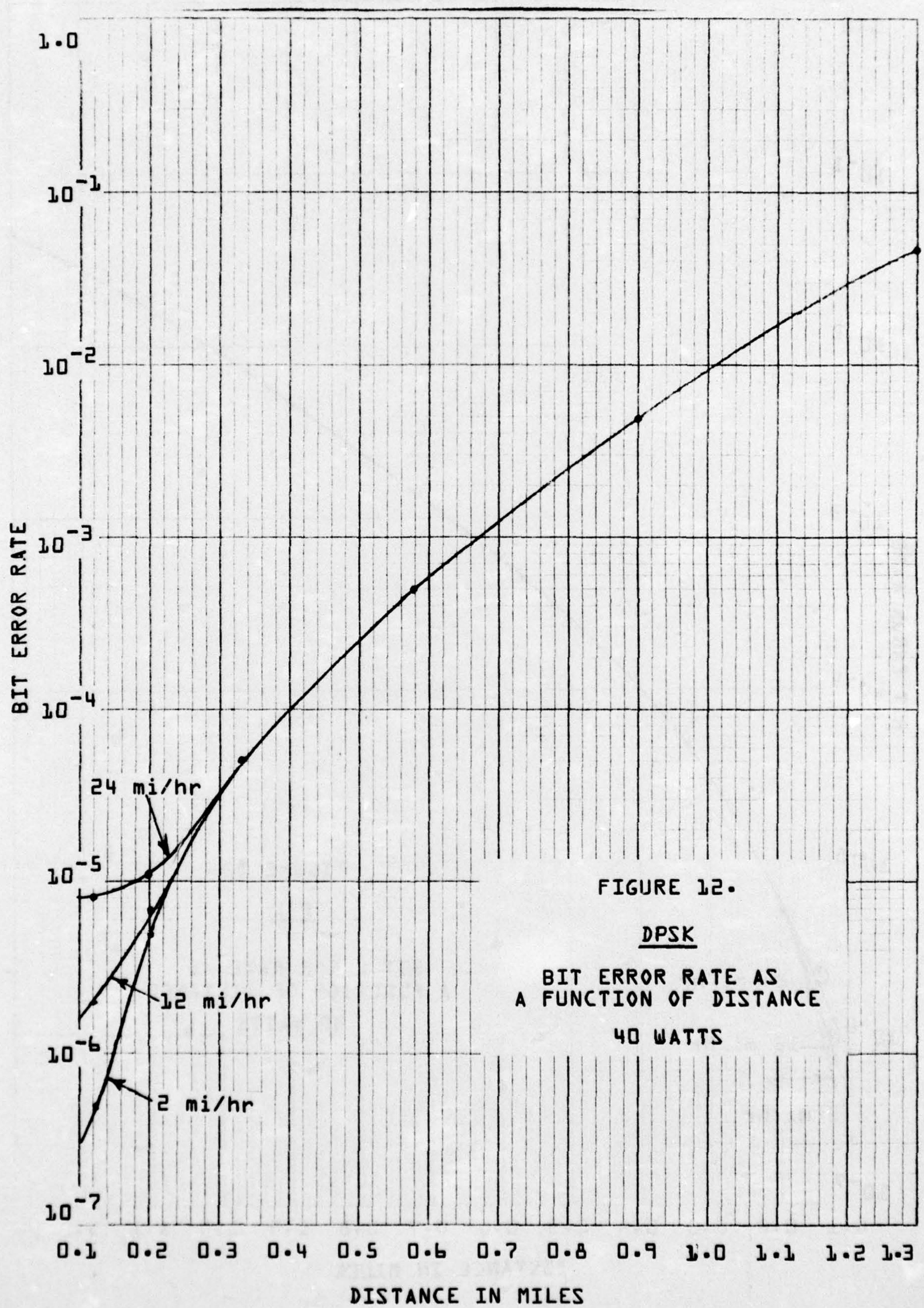


FIGURE 12.

DPSK

BIT ERROR RATE AS
A FUNCTION OF DISTANCE

40 WATTS

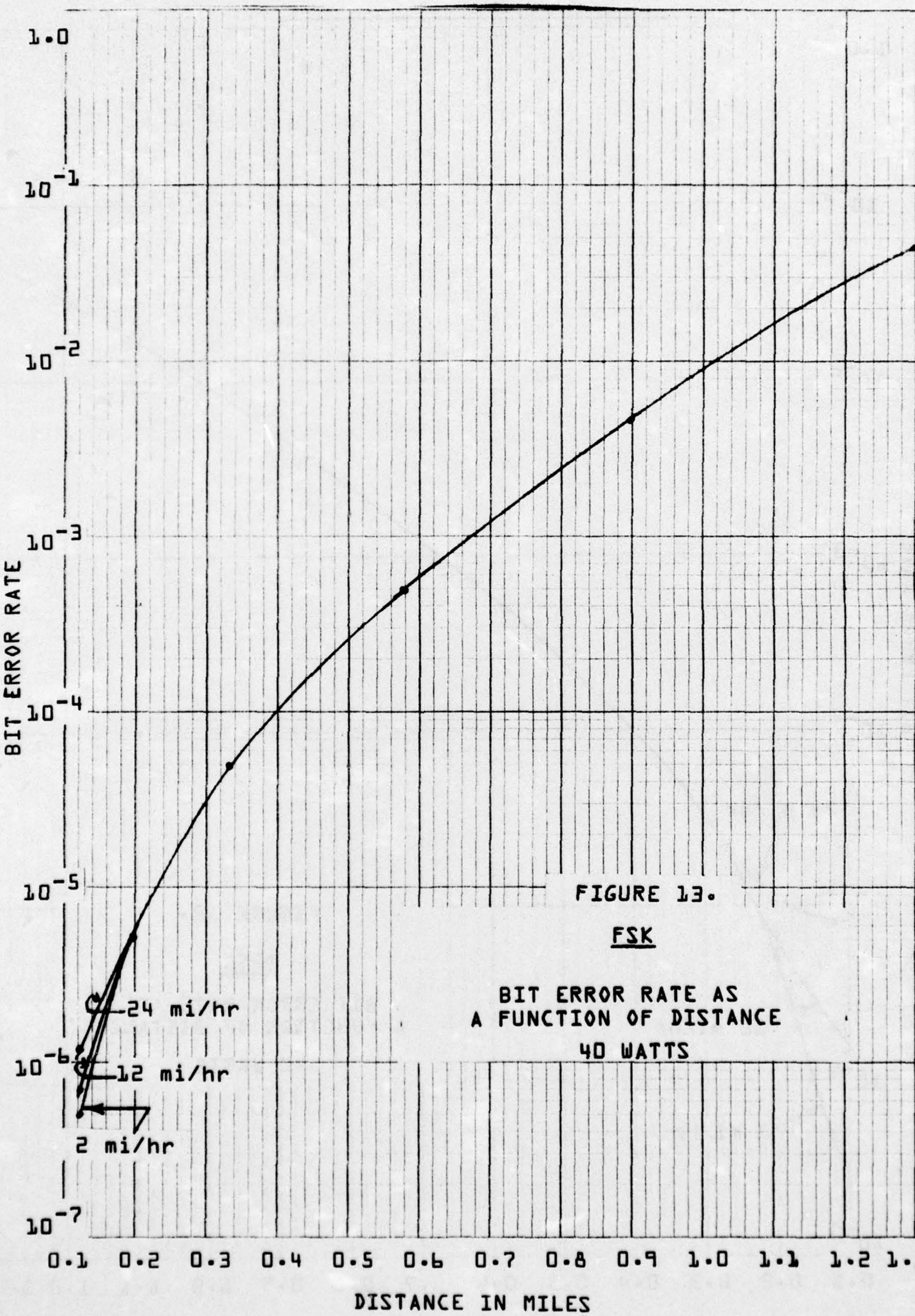


FIGURE 13.

FSK

BIT ERROR RATE AS A FUNCTION OF DISTANCE 40 WATTS